US Army Corps of Engineers
St. Louis District

CARROLL ISLAND MICRO MODEL STUDY
RIVER MILES 273.0 TO 263.0

HYDRAULIC MICRO MODEL INVESTIGATION

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Prepared for
U.S. Army Corps of Engineers, St. Louis District
Avoid and Minimize Program

In cooperation with:
ILLINOIS DEPARTMENT OF NATURAL RESOURCES
MISSOURI DEPARTMENT OF CONSERVATION
U.S. FISH AND WILDLIFE SERVICE
RIVER INDUSTRY ACTION COMMITTEE
Final Report - MAY 2006

APPLIED RIVER ENGINEERING CENTER

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INTRODUCTION

The U.S. Army Corps of Engineers, St. Louis District initiated a sedimentation improvement study of the Carroll Island reach of the Upper Mississippi River between Miles 273.0 and 263.0 near Clarksville, Missouri. The purpose of the study was to evaluate design alternatives to alleviate repetitive channel maintenance dredging associated with continual sediment deposition in the navigation channel while maintaining or improving existing environmental habitat. This study will utilize and/or modify the existing dike fields and incorporate new construction to optimize the energies associated with sediment transport in an attempt to reduce chronic dredging concerns.

Mr. Jasen L. Brown, hydraulic engineer, Ms. Dawn M. Lamm, hydraulic engineer, Mr. Edward H. Riiff, engineering technician, Mr. Andrew R. Richter, hydraulic engineer, and Mr. Jared M. Myers, engineering co-op, under direct supervision of Mr. David C. Gordon, hydraulic engineer, conducted the study between February 2004 and November 2004. Other personnel also involved with the study included: Mr. Robert D. Davinroy, District Potamologist, Mr. Leonard Hopkins, Project Manager, Avoid and Minimize Program; Mr. Brian Johnson and Mr. Kip Runyon from the Environmental Branch of the Planning, Programs, and Project Management Division. Personnel from other agencies involved in the study included: Mr. Butch Atwood from the Illinois Department of Natural Resources, and Ms. Joyce Collins and Mr. Mike Thomas from the U.S. Fish and Wildlife Service; Mr. Danny Brown from the Missouri Department of Conservation and Mr. Samuel Dickey from the River Industry Action Committee (RIAC).

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BACKGROUND

Micro modeling methodology was used to evaluate the present sediment transport conditions as well as the impact associated with the incorporation of future design alternatives along the Carroll Island Reach of the Middle Mississippi River. This study was funded as part of the Avoid and Minimize Program of the Upper Mississippi River. The primary goal of this study was to alleviate chronic dredging in the main channel adjacent to Carroll and Coon Island.

1. Study Reach

The Carroll Island reach is located immediately downstream of Lock and Dam 24 near Clarksville, Missouri. The study comprised a 10-mile stretch of the Upper Mississippi River, between Miles 273.0 and 263.0. Plate 1 is a location and vicinity map of the study reach. The study area was located in Pike County in Missouri, and Calhoun County in Illinois.

Plates 2 and 3 together are a 2003 aerial photograph illustrating the geomorphology and nomenclature of the Upper Mississippi River between Miles 273.0 and 263.0. This reach of river contains several islands and side channels, although it is not considered a braided channel. A controlling factor for this reach of river is the Clarksville Lock and Dam (Plate 4) at Mile 273.3. The dam consists of gates in the main channel, and an overflow spillway connecting the Illinois bank to the concrete dam structure. The 600 ft lock is along the Missouri bank. Also on the Missouri side, the right descending bank (RDB) consists of 300 to 400 ft high bluffs on the upstream end near the dam, with flat, levee-protected farmland on the downstream end. On the Illinois side, the entire reach consists of flat, levee-protected farmland (Plate 5).

Bankline revetment in this reach is also a controlling factor. Nearly all banklines in this reach are revetted. This revetment results in hard points along some banks and island heads, resulting in significant (up to -20 ft) scour at these locations.

Carroll Island Chute draws a significant amount of flow from the main channel (indicated in the Flow Distribution Data (Plate 8)), thus reducing the energy in the main channel. This lower energy condition causes shallower depths in the main channel and thus the need for frequent dredging. Plate 9 shows the areas of significant dredging and typical disposal sites. The most significant dredging areas are in the main channel adjacent to the upstream end of Carroll Island and adjacent to Coon Island. Dredging has been costlier and required at less frequent intervals adjacent to the middle and downstream end of Carroll Island.

2. Dredging and Alignment Analysis

This reach of the Mississippi River has been very troublesome. Dredging has occurred on an almost yearly basis in two locations. Plate 9 shows the dredge cut locations and disposal sites between Miles 270.8 to 268.2 and Miles 267.7 to 265.5 for the dredging that occurred between 1979 and 2004. Plate 10 shows a graph of the yearly dredging totals from 1979 to 2004 between Miles 227.6 and 265.8. Within this eight-mile reach, approximately 4.8 million cubic yards of material was dredged at a cost of nearly $6.8 million over a period of 26 years. That translated into a yearly average of over 185,000 cubic yards of material at a cost of nearly $262,000 per year. The area between Miles 270.8 and 268.2, just upstream and adjacent to the upper portion of Carroll Island, was dredged in 12 of the 26 years and accounted for 54% of the total volume and 49% of the total costs. The area adjacent and downstream of the lower portion of Carroll Island between Miles 267.7 and 265.5 was dredged in 17 of the 26 years and accounted for 46% of the total volume and 51% of the total cost. Data before 1978 was not analyzed because dredging records were not accurately kept before this time.

In 1999, three chevrons were constructed along the RDB between Mile 266.1 and Mile 265.8 (Plate 11). During that year, dredging adjacent to Coon Island was not required. In 2001 a substantially reduced volume of material (when compared to previous yearly totals) was side-cast. No further dredging was required between

2001 and 2003. This data would suggest that the chevrons are having a positive effect on maintaining adequate channel depth and width for navigation.

This dredge material was typically side-cast into adjacent dike fields along the right banks of Carroll Island and Coon Island, which is the LDB of the main channel. However, these dike fields can only hold so much material and eventual high water events may flush material downstream and cause increased problems for areas already experiencing maintenance dredging.

Alignment of the main channel with the islands and side channels is another cause for repetitive dredging. Due to repetitive dredging and artificial channel placement between Mile 270.0 and Mile 266.0, the natural location of the channel thalweg can only be generally inferred through river engineering experience.

3. Flow Distribution Analysis

Recent discharge measurements have revealed a relatively steady percentage of the total flow, between 35 and 40 percent, is within the Carroll Island Chute. Plate 8 displays flow split measurements collected at Miles 266.5 and 264.0 between 1994 and 2004. Each colored bar shows the percentage of total discharge handled by each channel throughout the years. It is reasonable to assume that, with 50 percent or less of the total flow not passing through the approximately 1750 foot wide main channel, there is insufficient energy remaining to maintain the required 9 foot navigation channel adjacent to Carroll Island and Coon Island.

4. History

1880

Plate 12 shows the 1880 planform for the Carroll Island reach. In 1880, the Carroll Island reach consisted of several islands and side channels, with an overall width (islands included) that varied from a minimum of approximately 4500 feet, to a maximum of 6500 feet. Construction of Lock and Dam 24 did not begin until 1936; therefore open river conditions existed throughout the reach. Just a few river training structures were shown on the 1880 survey. These structures were located only in side channels and thus served only to restrict side channel flow to allow for increased energy and depth in the main channel. Side channel closure structures existed at the entrance to Clarksville Chute (Mile 273.2), in the upstream section of Carroll Island Chute (Mile 268.9), at the entrance to Slim Chute (Mile 267.5), and connecting the head of Grimes Island to Slim Island (Mile 266.0).

1947

Plate 13 shows the 1947 planform for the Carroll Island reach. Construction of Lock and Dam 24 was completed in 1940. Lock and Dam 24 was a controlling factor for the bathymetry shown in the 1947 survey. Another lock and dam structure, Lock and Dam 25, had been completed in 1939 at Mile 241.4. These dams significantly altered the flows into the Carroll Island reach and created pool conditions as opposed to open river conditions during low flows. Only when both Lock and Dam 24 and Lock and Dam 25 have all their gates out of the water would the river flow be in open river conditions.

1968

Plate 14 shows the planform and bathymetry of the Carroll Island reach in 1968. The morphology of the Carroll Island was the only significant difference between 1968 and 1947. Pile dike structures extending from the LDB toward the main channel from Carroll Island caused accretion leading to vegetation and definite island boundaries.

1977

Plate 15 shows the planform and bathymetry of the Carroll Island reach in 1977. No significant differences existed between the 1977 bathymetry and island layout and the 1968 bathymetry and island layout.

1982

Plate 16 shows the planform and bathymetry of the Carroll Island reach in 1982. No significant differences existed between the 1982 bathymetry and island layout and the 1977 bathymetry and island layout.

1986

Plate 17 shows the planform and bathymetry of the Carroll Island reach in 1986. No significant differences existed between the 1986 bathymetry and island layout and the 1982 bathymetry and island layout.

1993

Plate 18 shows the planform and bathymetry of the Carroll Island reach in 1993. No significant differences existed between the 1993 bathymetry and island layout and the 1986 bathymetry and island layout. However, a portion of the repetitive dredging location is evident between Mile 270.2 and Mile 268.5.

1995

Plate 19 shows the planform and bathymetry of the Carroll Island reach in 1995. The 1995 hydrographic survey showed shallower water between Mile 269.0 and Mile 270.0 when compared to previous surveys. This is likely due to the timing of the survey just before a dredge cut as opposed to just after. No side channel information is shown on the 1995 hydrographic survey. However, a portion of the repetitive dredging location is evident between Mile 268.5 and Mile 268.8.

1997

Plate 20 shows the planform and bathymetry of the Carroll Island reach in 1997. The 1997 hydrographic survey was similar to the 1993 and 1995 hydrographic surveys, although no side channel information is shown on the 1997 hydrographic survey.

1999

Plate 21 shows the planform and bathymetry of the Carroll Island reach in 1999. The 1999 hydrographic survey was similar to the 1997 hydrographic survey.

5. Study Purpose and Goals

The purpose of this study was to assess the current sediment transport conditions in the Carroll Island reach, evaluate the interaction between the main channel and the side channel complex, and provide a solution or solutions to achieve the project goal of reducing the need for repetitive dredging. The area of repetitive dredging is located in the main channel between Mile 270.5 and Mile 266.0. Preservation of adequate side channel depth is also a goal of this study. Side channel bathymetries should, if possible, remain unchanged while the existing energy in the main channel should be focused in order to provide adequate channel location, width, and depth for navigation.

MICRO MODEL DESCRIPTION

1. Scales and Bed Materials

In order to investigate the sediment transport conditions described previously, a physical hydraulic micro model was designed and constructed. Plate 22 is a photograph of the hydraulic micro model used in this study. The zero reference plane of the prototype was assumed to be the MP (Minimum Pool) condition. The model employed a horizontal scale of 1 inch = 800 feet, or 1:9600, and a vertical scale of 1 inch = 27 feet, or 1:324, for a 30 to 1 distortion ratio of linear scales. This distortion supplied the necessary forces required for the simulation of sediment transport conditions similar to those of the prototype. The bed material was granular plastic urea, Type II, with a specific gravity of 1.40.

2. Appurtenances

The micro model insert was constructed according to the 1995 high-resolution aerial photography of the study reach shown as a background on Plates 18-21, and Plates 23-42. The insert was then mounted in a standard micro model hydraulic flume. The riverbanks of the model were constructed from dense polystyrene foam, and modified during calibration with galvanized steel mesh. Rotational jacks located within the hydraulic flume controlled the slope of the model. The measured slope of the insert and flume was approximately 0.00625 inch/inch. River training structures in the model were made of galvanized steel mesh.

Flow into the model was regulated by customized computer hardware and software interfaced with an electronic control valve and submersible pump. This interface was used to automatically control the flow of water and sediment into the model. Discharge was monitored by a magnetic flow meter interfaced with the customized computer software. Water stages were manually checked with a mechanical three-dimensional point digitizer. Resultant bed configurations were measured and recorded with a three-dimensional laser digitizer.

MICRO MODEL TESTS

1. Model Calibration

The calibration of the micro model involved the adjustment of water discharge, sediment volume, model slope, and entrance conditions of the model. These parameters were refined until the measured bed response of the model was similar to that of the prototype.

A. Micro Model Operation

In all model tests, a steady state flow was simulated in the Middle Mississippi River channel. This served as the average design energy response of the river. Because of the constant variation experienced in the prototype, this steady state flow was used to theoretically analyze the ultimate expected sediment response. The flow was held steady at a constant flow rate of 2.50 GPM during model calibration and for all design alternative tests. The most important factor during the modeling process is the establishment of an equilibrium condition of sediment transport. The high steady flow in the model simulated an average energy condition representative of the river's channel forming flow and sediment transport potential at bankfull stage.

B. Prototype Data and Observations

To determine the general bathymetric characteristics and sediment response trends that existed in the prototype, several present and historic hydrographic surveys were examined. Plates 18 through 21 are plan view hydrographic survey maps of the Mississippi River from 1993, 1995, 1997, and 1999, respectively.

All four surveys showed similar bathymetric trends and thalweg location throughout the Carroll Island reach.

- An area of deep scour was observed at the exit of Lock and Dam 24.

- Between Mile 273.0 and 272.5, the thalweg crossed from the center of the main channel to the RDB.

- Between Mile 272.0 through Mile 271.3, depths increase significantly along the RDB as the channel thalweg is redirected toward the LDB. This channel crossing from the RDB to the LDB occurs between Mile 272.0 and Mile 271.0, resulting in the formation of a sandbar along the RDB at Mile 271.0.

- Increased depth was observed just downstream of this sandbar, around Mile 270.6, along the main channel bank of Eagle Island.

- The main channel thalweg appeared to cross from the RDB to the LDB in another complete crossing at about Mile 270.3. However, increased channel width and repetitive dredging from Mile 270.0 and downstream occurred near the middle of the main channel, with dredge spoil being placed along the LDB. Thus the channel thalweg was artificially maintained in the middle of the channel through Mile 268.7.

- At Mile 268.7, the channel thalweg crosses to the RDB.

- The channel thalweg remains along the RDB until Mile 267.2, where the river makes an eastward turn while the thalweg moves off the RDB and into the center of the main channel.

- At Mile 266.6, the thalweg returned to the RDB, only to cross over to the LDB between Mile 266.1 and Mile 265.2.

- Between Mile 265.2 and Mile 264.5 a deep scour hole was observed along the LDB. Significantly shallower water was observed along the LDB immediately downstream of this scour hole, while a separate scour hole formed along the RDB (Mile 264.2).

- Finally, another deep scour hole was observed in the center of the channel in a narrow reach between Mile 263.8 and 263.0.

2. Base Test

Model calibration was achieved once favorable qualitative comparisons of the prototype surveys were made to several surveys of the model. The resultant bathymetry of this bed response served as the base test of the micro model.

Plate 23 shows the resultant bed configuration of the micro model base test. The base test was developed once bed stability was reached and a similar bed response was achieved as compared with prototype surveys. This survey then served as the comparative bathymetry for all design alternative tests.

Results of the micro model base test bathymetry and a comparison to the 1993 through 1999 prototype surveys indicated the following trends:

- Between Mile 273.0 and 270.0, the main channel bathymetry and thalweg location match the prototype. The bar formation at Mile 271.0 along the RDB was slightly larger and shallower (+2 ft) than in the prototype. Also, the middle section of Clarksville Chute was deeper in the model when compared to the most recent (1993) prototype survey that included the Clarksville Chute.

- Repetitive dredging and artificial thalweg placement in this reach heavily influenced all prototype surveys from Mile 270.0 through Mile 268.5. Between 1993 and 1999, the prototype surveys showed varying states of deposition in this reach. The 1993 bathymetry indicated shallow water (-8 ft MP) between Mile 269.5 and Mile 268.7. Small scour holes (-12 ft MP) were also observed in this reach along the LDB near the head of Carroll Island, and along the RDB face of Amaranth Island. The 1995 bathymetry shows shallow water across the main channel at Mile 268.7. At Mile 270.0, the base test bathymetry is similar to that of the prototype. Just downstream of the head of Carroll Island, at Mile 269.8, the base test shows a large line of scour along the LDB face of Carroll Island. This line of scour reaches a depth of –18 ft., extends downstream approximately 0.6 miles, and can only be inferred to be indicative of the prototype bathymetry’s ultimate bed response with no dredging. Shallow water, -8 ft MP and shallower, is prevalent from Mile 269.0 and downstream for approximately 1.0 miles. Plate 24 shows the simulated dredging condition in the model. The thalweg was placed artificially near the center of the channel in both dredging locations similar to the artificial thalweg placement in the prototype.

- Between Mile 268.0 and Mile 267.0, the thalweg followed along the RDB with depths of between 10 feet MP and –12 feet MP. Prototype surveys indicated a scour hole along the RDB at Mile 267.5. Although the Base Test showed the thalweg in the proper location, it was shallower. This phenomenon can be attributed to the fact that the model represented the ultimate bed response of the prototype assuming no dredging upstream. It is assumed that artificial channel creation upstream may influence bathymetry patterns downstream.

- Between Mile 267.0 and 266.0, the main channel thalweg was located along the RDB in both the model and the prototype. Additional depth was observed in the model versus the prototype, but again this can be attributed to the affect of repetitive dredging upstream of this reach in the prototype. The construction of the Chevrons at Mile 266.0 could be having an effect on the bathymetry pattern of this reach, although at the time of the writing of this report only limited survey information in and around the chevrons was available.

- At Mile 266.0, the main channel thalweg was observed to cross from the RDB to the LDB and cause a deep scour hole along the LDB between Mile 265.5 and Mile 264.5 in the prototype. These same trends were replicated in the model base test, with the only significant difference being a large scour hole located at the exit to Carroll Island Chute. A large bar formation at a depth of –10 ft MP was observed in both the model and prototype at Mile 264.5, while significant channel narrowing and depth was observed downstream of Mile 264.0 in the model and prototype.

- The side channels of the Carroll Island reach, including Clarksville Chute, Carroll Island Chute, and Slim Chute, all showed significant depth in the model. Depths were generally –10 ft MP and shallower, although some deeper scour was observed just downstream of overtopped closure structures. In prototype surveys that included side channel bathymetries, most notably 1993, Clarksville Chute and Slim Chute were 2 to 6 ft. shallower. Throughout the length of Carroll Island Chute, the model was similar in bathymetry to the 1993 prototype survey.

Overall, the trends of the model as observed in the base test were similar to those observed from the prototype surveys, especially in the reaches of river just upstream and just downstream of the repetitive dredging areas adjacent to Carroll Island.

3. Design Alternative Tests

Eighteen design alternative plans were model tested to examine methods of modifying the sediment transport response trends that would help alleviate the need for repetitive dredging within the navigation channel. The effectiveness of each design was evaluated by comparing the resultant bed configuration to that of the base condition. Impacts or changes induced by each alternative were evaluated by observing the sediment response of the model. A qualitative evaluation of the ramifications to the main channel and the side channel was made during team participation meetings at the Applied River Engineering Center in St. Louis, Missouri. Personnel from the St. Louis District Corps of Engineers, Missouri Department of Conservation, Illinois Department of Natural Resources, U.S. Fish and Wildlife Service, and River Industry Action Committee carefully examined and discussed each alternative.

Alternative 1: (Plate 25)

Type of Structure	Number of Structures	Miles	LDB or RDB	Dimensions in Feet	Height in Feet MP
Chevrons	4	270.1 269.3 268.8 268.2	RDB RDB RDB RDB	300 x 300	+4

Effect on Dredging at Mile 270.0-268.0	Effect on Dredging at Mile 267.0-266.0	Effect on Carroll Island Chute	Additional Comments
Increased Depths	Decreased Depths	None	This test improved the upstream dredging reach, although it did not completely open a channel suitable for navigation. The downstream dredging reach was worsened by this alternative, becoming shallower at Mile 266.2.

<u>Alternative 2: (Plate 26)</u>

Type of Structure	Number of Structures	Miles	LDB or RDB	Dimensions in Feet	Height in Feet MP
Chevrons	6	270.1 269.6 269.3 268.8 268.4 268.2	LDB RDB LDB LDB RDB LDB	300 x 300	+4

Effect on Dredging at Mile 270.0-268.0	Effect on Dredging at Mile 267.0-266.0	Effect on Carroll Island Chute	Additional Comments
Increased Depths	Decreased Depths	None	This test improved the upstream dredging reach, completely opening a channel suitable for navigation. The downstream dredging reach was worsened by this alternative, becoming shallower at Mile 266.2.

Alternative 3; (Plate 27)

Type of Structure	Number of Structures	Miles	LDB or RDB	Dimensions in Feet	Height in Feet MP
Chevrons	7	270.1 269.3 268.8 268.4 268.2 267.3 266.3	LDB LDB LDB RDB LDB RDB RDB	300 x 300	+4

Effect on Dredging at Mile 270.0-268.0	Effect on Dredging at Mile 267.0-266.0	Effect on Carroll Island Chute	Additional Comments
Increased Depths	Decreased Depths	None	This test improved the upstream dredging reach, although it did not completely open a channel suitable for navigation. The downstream dredging reach worsened by this alternative, becoming shallower at Mile 265.9.

Alternative 4: (Plate 28)

Type of Structure	Number of Structures	Miles	LDB or RDB	Dimensions in Feet	Height in Feet MP
Chevrons	9	270.1 269.3 268.8 268.4 268.2 267.3 267.0 266.5 266.4	LDB LDB LDB RDB LDB RDB LDB RDB RDB	300 x 300	+4

Effect on Dredging at Mile 270.0-268.0	Effect on Dredging at Mile 267.0-266.0	Effect on Carroll Island Chute	Additional Comments
Increased Depths	Increased Depths, Narrow Width	None	This test improved the upstream dredging reach, completely opening a channel suitable for navigation. The downstream dredging reach was improved by this alternative, becoming deeper throughout. This alternative would be restrictive in navigation channel width, however, with a navigable channel width of only 400 ft. at Mile 266.5.

Alternative 5: (Plate 29)

Type of Structure	Number of Structures	Miles	LDB or RDB	Dimensions in Feet	Height in Feet MP
Chevrons	6	270.1 269.3 268.4 268.2 268.0 267.3 266.5	LDB LDB RDB LDB RDB RDB RDB	300 x 300	+4
Raised Dike	1	268.9		530	+4

Effect on Dredging at Mile 270.0-268.0	Effect on Dredging at Mile 267.0-266.0	Effect on Carroll Island Chute	Additional Comments
Increased Depths	Increased Depths	None	This test improved the upstream dredging reach, completely opening a channel suitable for navigation. The downstream dredging reach improved with this alternative, with a 10 ft. navigation channel opened up throughout.

Alternative 6: (Plate 30)

Type of Structure	Number of Structures	Miles	LDB or RDB	Dimensions in Feet	Height in Feet MP
Chevrons	4	272.6 271.4 270.1 266.4	RDB RDB LDB RDB	300 x 300	+4

Effect on Dredging at Mile 270.0-268.0	Effect on Dredging at Mile 267.0-266.0	Effect on Carroll Island Chute	Additional Comments
Increased Depths	Increased Depths	None	This test improved the upstream dredging reach, although it did not completely open a channel suitable for navigation. The downstream dredging reach was improved by this alternative, resulting in a narrow (300 ft) but adequately deep (-10 ft MP) navigation channel.

<u>Alternative 7: (Plate 31)</u>

Type of Structure	Number of Structures	Miles	LDB or RDB	Dimensions in Feet	Height in Feet MP
Chevrons	7	270.1 270.0 269.6 269.3 268.8 266.2 266.4	LDB LDB LDB LDB LDB LDB LDB	300 x 300	+4

Effect on Dredging at Mile 270.0-268.0	Effect on Dredging at Mile 267.0-266.0	Effect on Carroll Island Chute	Additional Comments
Increased Depths	None	None	This test improved somewhat the upstream dredging reach, almost completely opening a channel suitable for navigation. The downstream dredging reach was not affected by this alternative.

Alternative 8: (Plate 32)

Type of Structure	Number of Structures	Miles	LDB or RDB	Dimensions in Feet	Height in Feet MP
Chevrons	7	270.0 269.6 269.3 268.8 268.4 267.4 266.4	LDB LDB LDB LDB LDB RDB RDB	300 x 300	+4

Effect on Dredging at Mile 270.0-268.0	Effect on Dredging at Mile 267.0-266.0	Effect on Carroll Island Chute	Additional Comments
Increased Depths	Increased Depths	None	This test improved the upstream dredging reach somewhat, nearly completely opening a channel suitable for navigation. The downstream dredging reach was improved by this alternative, becoming deeper throughout with a narrow passage past the chevron at 266.4R.

Alternative 9: (Plate 33)

Type of Structure	Number of Structures	Miles	LDB or RDB	Dimensions in Feet	Height in Feet MP
Chevrons	3	266.4 266.5 266.6	LDB LDB LDB	300 x 300	+4
Raised Dike	2	268.4 268.9	LDB LDB	625 500	+4

Effect on Dredging at Mile 270.0-268.0	Effect on Dredging at Mile 267.0-266.0	Effect on Carroll Island Chute	Additional Comments
Increased depths	None	None	This test improved the upstream dredging reach somewhat, completely opening a channel suitable for navigation. The downstream dredging reach was not improved with this alternative.

Alternative 10: (Plate 34)

Type of Structure	Number of Structures	Miles	LDB or RDB	Dimensions in Feet	Height in Feet MP
Chevrons	9	270.0 269.8 269.6 269.0 268.8 268.5 268.2 268.0 267.0	LDB LDB LDB LDB LDB LDB LDB LDB LDB	300 x 300	+4
Raised Dikes	1	267.2	RDB	530	+4
New Dikes	4	267.3 266.7 266.5 266.3	RDB RDB RDB RDB	500 250 350 675	+4

Effect on Dredging at Mile 270.0-268.0	Effect on Dredging at Mile 267.0-266.0	Effect on Carroll Island Chute	Additional Comments
Increased Depths	Increased Depths	None	This test improved the upstream dredging reach, deepening but not completely opening a channel suitable for navigation. The downstream dredging reach improved with this alternative, with a 10 ft. navigation channel opened up throughout.

Alternative 11: (Plate 35)

Type of Structure	Number of Structures	Miles	LDB or RDB	Dimensions in Feet	Height in Feet MP
Chevrons	10	270.0 269.8 269.6 269.0 268.7 268.4 267.6 267.5 267.4	LDB LDB LDB LDB RDB RDB RDB RDB RDB	300 x 300	+4
Raised Dikes	1	267.2	LDB	530	+4
New Dikes	3	266.7 266.5 266.3	RDB RDB RDB	250 350 675	+4

Effect on Dredging at Mile 270.0-268.0	Effect on Dredging at Mile 267.0-266.0	Effect on Carroll Island Chute	Additional Comments
Increased Depths	Increased Depths	None	This test improved the upstream dredging reach, deepening but not completely opening a channel suitable for navigation. The downstream dredging reach improved with this alternative, with a 10 ft. navigation channel opened up throughout.

Alternative 12: (Plate 36)

Type of Structure	Number of Structures	Miles	LDB or RDB	Dimensions in Feet	Height in Feet MP
Chevrons	10	270.3 269.8 269.3 269.0 268.7 268.5 268.2 268.0 267.3	LDB LDB LDB LDB RDB RDB RDB RDB RDB	300 x 300	+4
Raised Dikes	1	267.2	LDB	530	+4
New Dikes	3	266.7 266.5 266.3	RDB RDB RDB	250 350 675	+4

Effect on Dredging at Mile 270.0-268.0	Effect on Dredging at Mile 267.0-266.0	Effect on Carroll Island Chute	Additional Comments
Increased Depths	Increased Depths	None	This test improved the upstream dredging reach, deepening and completely opening a channel suitable for navigation. Also possible new dredging issues created at Mile 267.2. The downstream dredging reach improved with this alternative, with a 10 ft. navigation channel opened up throughout.

Alternative 13: (Plate 37)

Type of Structure	Number of Structures	Miles	LDB or RDB	Dimensions in Feet	Height in Feet MP
Chevrons	10	270.0 269.8 269.6 269.0 268.7 268.4 267.6 267.5 267.4	LDB LDB LDB LDB RDB RDB RDB RDB RDB	300 x 300	+4
Raised Dikes	1	267.2	LDB	530	+4
New Dikes	3	266.7 266.5 266.3	RDB RDB RDB	250 350 675	+4

Effect on Dredging at Mile 270.0-268.0	Effect on Dredging at Mile 267.0-266.0	Effect on Carroll Island Chute	Additional Comments
Increased Depths	Increased Depths	None	This test improved the upstream dredging reach, deepening but not completely opening a channel suitable for navigation. The downstream dredging reach improved with this alternative, with a 10 ft. navigation channel opened up throughout.

Alternative 14: (Plate 38)

Type of Structure	Number of Structures	Miles	LDB or RDB	Dimensions in Feet	Height in Feet MP
Chevrons	7	272.9 272.7 272.5 269.7 269.7 269.0 268.8	LDB LDB LDB RDB LDB LDB LDB	300 x 300	+4

Effect on Dredging at Mile 270.0-268.0	Effect on Dredging at Mile 267.0-266.0	Effect on Carroll Island Chute	Additional Comments
Increased Depths	Increased Depths	None	This test improved the upstream dredging reach, deepening but not completely opening a channel suitable for navigation. The downstream dredging reach improved with this alternative, with a 10 ft. navigation channel opened up throughout, but with a less than optimal alignment.

Alternative 15: (Plate 39)

Type of Structure	Number of Structures	Miles	LDB or RDB	Dimensions in Feet	Height in Feet MP
Chevrons	2	271.2 270.5	RDB LDB	300 x 300	+4
Raised Dikes	4	269.8 268.9 268.7 268.4	LDB	430 375 450 500	+4
New Dikes	1	266.3	RDB	430	+4

Effect on Dredging at Mile 270.0-268.0	Effect on Dredging at Mile 267.0-266.0	Effect on Carroll Island Chute	Additional Comments
Increased Depths	Increased Depths	None	This test improved the upstream dredging reach, deepening and completely opening a channel suitable for navigation. The downstream dredging reach improved with this alternative, with a 10 ft. navigation channel opened up throughout.

Alternative 16: (Plate 40)

Type of Structure	Number of Structures	Miles	LDB or RDB	Dimensions in Feet	Height in Feet MP
Chevrons	3	271.2 270.5 269.3	RDB LDB LDB	300 x 300	+4
Raised Dikes	3	269.7 268.8 268.6	LDB LDB LDB	430 375 450	+4
New Dikes	1	266.3	RDB	430	+4

Effect on Dredging at Mile 270.0-268.0	Effect on Dredging at Mile 267.0-266.0	Effect on Carroll Island Chute	Additional Comments
Increased Depths	Increased Depths	None	This test improved the upstream dredging reach, deepening and completely opening a channel suitable for navigation. The downstream dredging reach improved with this alternative, with a 10 ft. navigation channel opened up throughout.

<u>Alternative 17: (Plate 41)</u>

Type of Structure	Number of Structures	Miles	LDB or RDB	Dimensions in Feet	Height in Feet MP
Chevrons	4	271.2 270.5 269.3 266.3	RDB LDB LDB RDB	300 x 300	+4
Raised Dikes	3	269.7 268.8 268.6	LDB LDB LDB	430 375 450	+4

Effect on Dredging at Mile 270.0-268.0	Effect on Dredging at Mile 267.0-266.0	Effect on Carroll Island Chute	Additional Comments
Increased Depths	Increased Depths	None	This test improved the upstream dredging reach, deepening and completely opening a channel suitable for navigation. The downstream dredging reach improved with this alternative, with a 10 ft. navigation channel opened up throughout.

Alternative 18: (Plate 42)

Type of Structure	Number of Structures	Miles	LDB or RDB	Dimensions in Feet	Height in Feet MP
Raised Dikes	1	270.6	LDB	2400	+4

Effect on Dredging at Mile 270.0-268.0	Effect on Dredging at Mile 267.0-266.0	Effect on Carroll Island Chute	Additional Comments
Increased Depths	Increased Depths	None	This test did not improve the upstream dredging reach, and did not improve the downstream dredging reach. Also, significant shallowing was observed in the Carroll Island Chute.

CONCLUSIONS

1. Evaluation and Summary of the Model Tests

Several alternative design tests were conducted in the micro model. Each alternative was evaluated using the following three objectives:

1. The reduction in the need for repetitive dredging between Mile 270.0 and Mile 268.0.
2. The reduction in the need for repetitive dredging between Mile 267.0 and Mile 266.0.
3. Amount of accretion, if any, in Carroll Island Chute.

Test	Increased Depth at Upstream Dredging Location (Mile 270.0-268.0)	Increased Depth at Downstream Dredging Location (Mile 267.0-266.0)	Minimal Effect on Carroll Island Chute
Alternative 1	x		x
Alternative 2	x		x
Alternative 3	x		x
Alternative 4	x	x	x
Alternative 5	x	x	x
Alternative 6	x	x	x
Alternative 7	x		x
Alternative 8	x		x
Alternative 9	x		x
Alternative 10	x	x	x
Alternative 11	x	x	x
Alternative 12	x	x	x
Alternative 13	x	x	x
Alternative 14	x	x	x
Alternative 15	x	x	x
Alternative 16	x	x	x
Alternative 17	x	x	x
Alternative 18			

While ten alternatives did meet all criteria, other test results indicated that they were not the optimal solution for the remediation of the Carroll Island dredging issues. These other factors included the formation of new dredging locations, inadequate channel width, or an undesirable channel alignment.

Test	Did Not Fully Alleviate Dredging Areas	Possible New Dredging Area Created	Inadequate Channel Width	Undesirable Channel Alignment
Alternative 1	x		x	x
Alternative 2	x		x	x
Alternative 3	x		x	x
Alternative 4			x	
Alternative 5			x	
Alternative 6	x		x	x
Alternative 7			x	x
Alternative 8			x	
Alternative 9	x	x		x
Alternative 10	x	x		
Alternative 11	x	x		
Alternative 12		x	x	
Alternative 13	x	x		
Alternative 14			X	x
Alternative 15				
Alternative 16				
Alternative 17				x
Alternative 18	x		x	x

Alternatives 15, 16, and 17 (Plates 39, 40, and 41, respectively) were successful in the satisfaction of all three design criteria without the creation of any of the aforementioned additional problems. In all three alternatives, two chevron structures were utilized between Mile 271.2 and Mile 270.5 in order to produce an effective channel alignment toward the structures along the LDB at the upstream dredging location. These structures helped to slightly decrease channel width, which resulted in additional depth in what was a shallow location. One additional structure along the RDB at the downstream dredging location was successful in adding additional depth and an improved channel alignment.

When compared to Alternative 15, Alternatives 16 and 17 produced slightly more depth between Mile 268.0 and Mile 270.0. Also, Alternative 16 produced a straighter channel alignment between Mile 267.0 and Mile 265.7 than Alternative 17. These two factors make Alternative 16 the preferable solution to the repetitive dredging adjacent to Carroll Island.

2. Recommendations

Alternative 16 (Plate 40) is the recommended plan to solve the dredging problems of the Carroll Island Reach. In Alternative 16, 3 chevrons, 3 raised dikes, and 1 new dike are utilized. The structures are configured as follows:

- Construct a Chevron at Mile 271.2 at a height of +4 MP, with the apex located approximately 300 feet off the RDB.
- Construct a Chevron at Mile 270.5 at a height of +4 MP, with the apex located approximately 1100 feet from the LDB.
- Raise Dike 269.7 (L) to +4 MP.
- Construct a Chevron at Mile 269.3 at a height of +4 MP, with the apex located approximately 400 feet from the LDB.
- Raise Dike 268.8 (L) to +4 MP.
- Raise Dike 268.6 (L) to +4 MP.

- Construct a new, 425 foot Dike to a height of +4 MP at Mile 266.3 extending from the RDB.

It is recommended that in implementing these structures into the Carroll Island Reach, a phased construction approach should be followed. This is especially true for the new Dike to be constructed at Mile 266.3. Important biological habitat exists in the chevron structures just downstream of this dike, thus a phased construction is recommended. A phased construction will allow for getting the maximum benefit from the structure without unnecessarily impacting this habitat. In addition, a close monitoring program of navigation channel conditions both before and after construction should be incorporated.

3. Interpretation of Model Test Results

In the interpretation and evaluation of the results of the tests conducted, it should be remembered that the results of these model tests were qualitative in nature. Any hydraulic model, whether physical or numerical, is subject to biases introduced as a result of the inherent complexities that exist in the prototype. Anomalies in actual hydrographic events, such as prolonged periods of high or low flows are not reflected in these results, nor are complex physical phenomena, such as the existence of underlying rock formations or other non-erodible variables. Flood flows were not simulated in this study.

This model study was intended to serve as a tool for the river engineer to guide in assessing the general trends that could be expected to occur in the actual river from a variety of imposed design alternatives. Measures for the final design may be modified based upon engineering knowledge and experience, real estate and construction considerations, economic and environmental impacts, or any other special requirements.

FOR MORE INFORMATION

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APPENDIX OF PLATES

Plate #'s 1 through 42 follow:

1. Location and Vicinity Map of the Study Reach
2. 2003 Aerial Photography
3. 2003 Aerial Photography
4. Photographs of the Clarksville Island Reach
5. Photographs of the Carroll Island Reach
6. Photographs of the Slim Island Reach
7. Photograph of the Island at River Mile 266.0
8. Yearly Flow Split Measurements, 1994 to 2004 at River Miles 266.5 and 264.0
9. Dredging Cut and Disposal Sites, 1987-2004
10. Yearly Dredging Totals and Costs, 1979 to 2001 River Miles 270.8 - 265.5
11. Photographs of the Chevrons at River Mile 266.0
12. 1880 Hydrographic Survey
13. 1947 Hydrographic Survey
14. 1968 Hydrographic Survey
15. 1977 Hydrographic Survey
16. 1982 Hydrographic Survey
17. 1986 Hydrographic Survey
18. 1993 Hydrographic Survey
19. 1995 Hydrographic Survey
20. 1997 Hydrographic Survey
21. 1999 Hydrographic Survey
22. Caroll Island Micro Model
23. Base Test
24. Simulated Dredging
25. Alternative 1
26. Alternative 2
27. Alternative 3
28. Alternative 4

29. Alternative 5
30. Alternative 6
31. Alternative 7
32. Alternative 8
33. Alternative 9
34. Alternative 10
35. Alternative 11
36. Alternative 12
37. Alternative 13
38. Alternative 14
39. Alternative 15
40. Alternative 16
41. Alternative 17
42. Alternative 18